NWX-NASA-JPL-AUDIO-CORE

Moderator: Jeff Nee
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Coordinator: Thank you all for standing by. We would like to inform you that today's call is being recorded. If you do have any objections, please disconnect at this time. Your lines are all open and interactive. If you would like to mute your line, it is star six to mute and unmute. Thank you.

Jeffrey Nee: Great. Okay, well, welcome everybody. Happy Tuesday. I'm Jeff Nee from the Museum Alliance and it is our great pleasure to host this telecon today. Thank you to all of you for joining us and to anyone listening to the recording in the future. Today we'll be talking about “Artificial Spatter Piles: Constraining Cooling and Rruption Rates in Idaho and on the Moon.” The slides for today's presentation can be found on the Museum Alliance and Solar System Ambassador sites. There are a few movies and animations in the presentation. So we recommend you use the PowerPoint if you can. Otherwise, we pulled out the movies as separate files for those using the PDF. So make sure you have those queued up and you're ready to use them at the right time.

If you have any problems at all, you can always email me. My email is jnee@jpl.nasa.gov. And as a final reminder, please do not put us on hold even if you have to step away, because some phones play holding music, which can disrupt the talk. Just be sure your phone is on mute so that no noises from your end interrupt the speakers. If you'd like to do one final check that you are, in fact, muted you may simply say your name into the phone right now and we'll let you know if we hear you. Great, I love silence before a telecon.

Our speaker today is Dr. Erika Rader. Erika is a postdoctoral researcher at NASA Ames Research Center in Mountain View, California. She got her PhD in geological sciences from the University of Idaho and she has worked with science teachers to develop field based curriculum and activities for K-12 classrooms, as well as interactive lectures that promote comprehension, but also critical thinking related to the role geology has in society.

If you can, please hold all your questions until the end. And with that Erika, it's great to have you.

Erika Rader: [Slide 1] All right, thanks very much. So yes, I'm going to talk today about the project that I've been working on for this past year, but also a little bit of the data from this project is a spillover from my PhD. Okay, so a bunch of these slides have multiple -- you have to push/change the slide multiple times because there's little animations where various data pops up at different times and that was sort of to help break down some of these diagrams. So I apologize if it gets a little confusing later, but we will try to get through this.

[Slide 2] Okay, so we'll start off with the outline and if you click again you'll see that what is spatter becomes highlighted here. So what I want to just give you a little intro on is what exactly this volcanic product is.

[Slide 3] So if you go to the next slide, this is the one that has the GIF and what this is, is a very small fissure eruption that's occurring in this video in

Hawaii. So this is maybe half a foot tall. It's not very big at all. And these little blobs are getting shot up into the air, and what you can see, hopefully, is that as they fly up there they change color. They start as sort of the bright yellow and they turn more reddish as they go flying through the air, and that's because they're cooling.

So they cooled somewhat, but they're still fluid enough that they are able to deform and have some kind of -- they're slightly ductile but they still, because they've cooled, they have this rind, this skin around them that allows them to retain some of their shape.

[Slide 4] And the next slide shows two examples of some of the highly deformed characteristics of these clasts. So these are both actually spatter bombs because they're not actually fused to any other clasts in their deposit. That's what would make it an actual spatter deposit but I wanted to show you what these clasts look like without all the other clasts around them because it can be kind of hard to pick them out of a deposit.

So these are two examples of fairly large spatter bombs at Craters of the Moon [National Monument and Preserve] and you can see that that skin doesn't have a lot of holes or cracks. There's a little bit of cracking in it, but it's actually a fairly cohesive skin on these bombs.

[Slide 5] Okay, next slide. In this picture, you can see three of the big categories that we break volcanic products into. There's the lava that's right in the front of the picture, and that smooth lava is what we call a pahoehoe, a spiny pahoehoe type lava. And if you go back through the mid-level of the photo you'll see that it gets a lot lumpier and more rough. And that's a different kind of lava that we call ‘a’a. And then behind that you'll see a big cone, and on the left side of that cone, it has a more gradual slope and a much finer grain size. You can't really see individual pieces from a distance here in this photo. And that side of the slope is predominantly tephra or scoria, which is what we call the material that gets thrown out of a volcano and cools in the air very quickly. So by the time it lands, it's still -- it's very brittle and it can be broken up into pieces. So that’s material like cinder and ash.

And then on the right side of that cone you can see it looks very different, and has a very different morphology. The cone itself has a steeper side, and there's a lumpier looking texture. That's something that we call a spatter cap, or this top of the cone that's been capped in a spatter deposit. Spatter looks different than these other products and, we can see that from a very far distance as well as close-up. This makes it helpful for distinguishing these morphologies in planetary situations, for example.

[Slide 6] So what can it actually tell us?

[Slide 7] Well, if we continue on here, we should be on Slide 7. What it shows us is that when we find spatter, because it can only form in sort of narrow conditions, we know that it's got to be fairly close to a vent. A vent is really important. If you're mapping out lava flows, you want to know where the vent is, this is where it tells you a lot about the tectonics or the terrain of the system. Also, if you have spatter then you know that your eruption was somewhat explosive, and the size of those clasts can tell you how explosive sometimes. When they're really big, that means it must have been able to blow out a lot of material in big blobs.

How spatter looks is related to somewhat how much gas there was in an eruption. Of course, the gas in an eruption is important for a lot of reasons, both for understanding how explosive these volcanoes were, which has a hazard implication. Also it tells you whether there was water in the system at all, which is something that we're really interested in on other planets, especially how much water there was and how much interaction there was between volcanoes and water.

[Slide 8] The next slide illustrates how important finding a vent can be. This is a little cartoon map of Washington, Oregon, and Idaho and the grayish irregular blob in the middle, that outlines the Columbia River flood basalts, which was a very large eruption that coated that whole area in thousands and thousands of feet of basalt. Because it erupted so much material so quickly, the lava flow occurs in these layers, and they're all very flat. So there's not a typical cone where you can go and find the highest point and that must've been where it erupted from. So finding where this huge lava flow erupted from really required a lot of field mapping and locating things like spatter deposits, since those are found near vents.

This map was able to be produced with the dashed lines showing some of the vent regions based on being able to find this spatter. So spatter is really important for mapping potential.

[Slide 9] Okay, if we go to the next slide, you can click through this one. There should be three little planets showing up here. The first one is Mercury, the second one is Venus, and the third one is Mars. All three of these planets, plus our Moon, are very much dominated by basalt. So anything that we can figure out about basaltic eruptions is helpful for understanding the evolution of these different planetary bodies.

There're lots of ways that we do that on Earth with dating and geochemical data, but since we don't have that ability on these other planets, any kind of relationship between morphology and the things that we're interested in can be very helpful.

[Slide 10] If you go to the next slide, that was sort of the goal of my project. Can I take all of these morphology parameters, so the way that the clasts look, the way that the deposit looks, and can I relate that to the information that we're really interested in for chemistry and process, and age? Those are all things that we're really interested in for Earth eruptions, as well as these planetary eruptions.

So if we can figure out how to relate those things then that would make [morphology] a powerful tool for understanding the Moon, for example. Okay, next slide.

[Slide 11] I mentioned a couple of those basaltic morphologies before: lava, tephra, and spatter. Spatter is this cool one because it happens to form in very narrow conditions that are constrained on all edges by other parameters. So this is why it can be particularly useful for quantifying what we see in the field.

[Slide 12] If you go to the next slide, this slide shows you a bit of the theory behind what started this project. This is the idea that if you have a little spatter cone in the bottom here, and on the left side of that spatter cone you can see there's only a couple of spatter blobs being ejected out. And so that's a slow accumulating system. In that scenario we would expect to see much more rapid cooling of the deposit, as compared to the other side of the spatter cone, where you have a lot of accumulation occurring. In that scenario we're going to have cooling that occurs, but it's much slower. So these two conditions might be something that we can detect in these deposits, and if so, then we might be able to come up with a way to quantify how fast it takes to form spatter cones.

[Slide 13] This photo shows two examples within this spectrum of rapid cooling and slow cooling. On the left is a picture of a bottom side of a clast, and on the bottom side of that clast, there's an impression in the middle of the photo, and that's where a rock used to be and I had plucked it out. And you can see that in the left corner of that impression, here's a little bit of that rock left. That little bit actually fused to this other clast. So this is a clast that was still hot enough to be ductile and to form around these little rocks that became embedded in the bottom, but it was also hot enough to fuse a little bit between the clast of these two rocks.

And then on the right side, this is the underside of a spatter bed and the rocks were totally not -- you couldn't pull them off if you tried, which we did. So that's a good example of how there is this gradient between just moderately fused, or barely fused, on the left side to totally fused on the right side. Okay, so, to understand this go to the next slide.

[Slide 14 video] And this is a video slide and you might want to play this a couple of times. In this video, what you'll see is basically the way that a lava flow has been placed. But what it's showing you is how the crust on a lava flow forms. If you play the video, the little toe begins to creep across the screen. It's very hot right at the base, and as it continues to extend, the top surface begins to cool. It goes from a reddish color, and then, as you go back towards the older part of this flow, it gets into this gray silvery material.

This transition between the very molten material all the way to the partially solidified material is a temperature gradient, and somewhere within that gradient you past the glass transition temperature, and this is when the material changes from a ductile and squishy material. You can see that a person comes and steps on that toe just a little bit, and it deforms. It goes down -- sinks down under their foot and then, when they remove their foot, it kind of reinflates back. That shows you just how deformable that crust can be, that skin. And then after you pass that glass transition temperature, which is about 700 degrees in the situation that we're using, when you pass that glass transition temperature, the clast forms and becomes rigid and isn't able to really anneal, or move. It’s not ductile anymore at all.

So spatter is forming in this range here right at the end of this toe and we're getting to the ability to deform, but also the ability to retain the shape of that clast. Okay, so next slide.

Erika Rader: [Slide 15] Yes, Slide 15. This shows you the two axes of this graph that we're going to go through, and there will be a couple of pictures that pop up and then fly onto the graph. Basically, what has been proposed is that there's a relationship between cooling rate and accumulation rate for spatter clasts and for other volcanic products. What we're going to look at it is a picture here of an eruption and this is the most recent eruption in Iceland, and you can see that there're these very large fire fountains that are shooting lava straight up into the sky. There're little blobs that are coming off of this, but predominantly most of this material is landing sort of closer toward the viewer of the photo.

From that comes these rivers of lava. That's occurring because this fountain is producing so much material that it doesn't have time to cool off and form clasts at all. It just forms these lava flows and we call these clastogenic lava flows because they're generated from clasts, and this is an example of a very high accumulate rate. So that flow, or that eruption, if you hit the button again, the picture will fly into the graph at a region of high accumulation rate and fairly low cooling rate.

[Slide 16] Now, if you hit the button again, what you'll see is these lava flows. This is an outcropped view of the Columbia River Flood basalts that I've shown you that map of before. These are like a layer cake of lava flows. You can see their very distinct morphology. This is when you have an eruption that's producing so much material, that you don't really have a lot of clast formation at all. It's just flowing out and away from the vent, and we get these lava flows.

[Slide 17] Okay, so if you hit the button again, I believe this is Slide 17, now we have another picture another type of eruption. In this eruption, you can see that the little pieces of rock, the glowing rock being thrown out from the vent. As they are traveling away, they cool down. You can see that the brightness of their track cools. It becomes less bright, and when they actually hit on the left side of the picture, you'll see that these rocks, when they hit, they make a whole bunch of new tracks and that's because when they hit they're actually breaking apart. So these are little clasts that are cooling the air so much that they are actually solid by the time they hit, or they're brittle by the time they hit. That's going to be a situation where there's a lot of cooling going on.

If we hit the button again, you'll see that that eruption process actually goes over to the higher cooling rate region and a moderate accumulation rate somewhere in the middle there.

[Slide 18] Now, what these products actually look like, if you hit the button again, you'll see a picture of what these cinder clasts can look like. You can see that they're all broken up and they're not really stuck together. They're just piled on top of each other in this outcrop photo. This is what we expect to see from this kind of eruption, which is usually more of a strombolian type of eruption.

[Slide 19] Okay, now if we go to Slide 19, this is another style of eruption. This style, however, is an intermediate style. Where we're still throwing out fluid clasts but it's not accumulating so fast that we have a lava flow. If you hit the button again you'll see that it flies down into this little corner of the graph where you're actually constrained on the right side by this fast cooling type of eruption and you're constrained on the top by this fast accumulation rate. And then that leaves you basically with this this goldilocks zone of “not too fast, not too slow, not too hot, not too cold.” [See slide 22 for the complete graph.]

[Slide 20] If you hit the button again, then you'll see these little droplets, and if you hit the button again the droplets will become outlined. What you can see is that these are fairly small. They're about a centimeter wide, but they were accumulated fast enough, and they were hot enough, that they were able to stick to what they landed upon. They didn't completely weld and fuse into a little flow that dropped off of this. They were stuck there as little clasts instead.

[Slide 21] If you go to the next slide, there're some bigger clasts. This is in the outcrop view, and if you hit the button again, it will outline a couple of them for you. These are kind of hard to see, but the way that we can detect these clasts in the field is you go up to the rock and you find the really vesicular or porous part. Say for example, in that lower clast that is outlined, you can see that there're some big holes in it. Those are the bubbles, the vesicles that get stuck. They get trapped in those clasts because when that material is thrown out of a vent, the outside chills. That builds up this pressure inside because this gas that's still stuck inside is trying to expand and escape. So it pushes out this clast a little bit, but mostly it just causes these bubbles to grow inside.

That's the vesiculated core of those clasts and then as you go out towards the edge, you can see that the vesicles become smaller and smaller and you eventually get to this totally un-vesiculated rind on the outside. So that's what spatter clasts look like.

[Slide 22] If we go back to our diagram here on Slide 22, and you hit the button again…

[Slide 23] we can replace what the eruption was like with those eruptive products. Now, we have this pretty cool link between what we see in the field and what we think must have happened to produce that.

[Slide 24] If you hit the button again, then we can get the nice boring diagram that just has the words on there. And this is what has been hypothesized in the past. However, if you hit the button again, you can see there are no numbers on this diagram. There's no cooling rate that's associated with this. There's no accumulation rate that's associated with the transition between spatter and flow. So that was my goal: can I put numbers on this, and from that, can we start using where we find these products to get some information about eruption process.

[Slide 25] Okay, so the outline slide again. So now, I'm going to talk to you about how I actually went about figuring this relationship out.

[Slide 26] So fieldwork, we're jumping back and forth between the lab and the field here, but I'll just show you where the fieldwork was located. So both spots were in the Pacific Northwest. So we're going to zoom in here to the Washington, Oregon, Idaho area. There’re two lava flows that I studied the spatter at. One is in Oregon. It's right about below the “r” in Oregon and the other one is in Idaho, and if you go below the word Idaho, there's a broad snake river plain that makes a little smiley face smile. The black blob that's got some stringy legs coming off of it to the south there, that's the lava flow in Idaho.

[Slide 27] We'll zoom into both of those and we'll put those pictures together. So on the left is Devil's Garden, Oregon here, and on the right is Craters of the Moon, Idaho. And these are both youngish flows, 2,000 years old or so, and they both have very well preserved spatter. I was able to study the spatter there and compare that to some of the experimental stuff.

[Slide 28] If you go to the next slide, 28, you can see one of these big spatter ramparts, the cones that are made up of these spatter deposits. There's no evidence for lava flows, or tephral layers, no scoria in there at all. It's all just spatter. So whatever accumulation rate we get for what produces spatter, we can basically apply to the height of this feature and get at how long it would have taken to form this kind of feature.

[Slide 29] Okay, so the next slide. The way to compare old natural samples with a new process, you have to link them together with some kind of experiment, basically. What I was able to do is go to Syracuse University, and this is a photo of the furnace setup that they have there. It's a tilting, gas-powered furnace that can melt about 300 pounds of basalt at a time. And what we could do with it is you can pour it out, and pour it into a little lava flow. People have poured it onto different things, and around different things, and have stuck things into it, to really see what it is capable of.

[Slide 30 video] What we were going to do is we wanted to make this into spatter clasts. If you go to the next page, this is the video, and you can play the video. I'll try to sort of narrate through it for those of you who aren't watching it, but basically the lava is poured into the trough. Then what we have to do is we dump some of the gravel. It's the same starting material that's being melted in there, but we wanted to introduce some of the volatiles back in, as well as cool down that material because it's really very molten. So to get it to a more reasonable viscosity, we dump that gravel in and we mush it around with a big paddle. And when it's finally cool enough to form a reliable rind, we transfer it over to the spatter pile building area and then we do it all over again.

This is sped up a little bit, but you can see just how fluid that material is. The other thing to note here is you can see there're little bubbles being blown. It's blowing its own bubbles. That's the water that's being released from the gravel that we're putting in there. That's providing all of gas, making the vesicles inside of those bombs. After we make these bombs, you can see there's a long thermocouple that's sticking out. We placed thermocouples between the clasts, and those are those long rods that are sticking out of there. That way we can measure the temperature inside of the pile as it's cooling off. Then Chris here with the FLIR camera, he's taking pictures from the outside of the pile so that you can get the thermal history of the surface.

[Slide 30] If you go to the next slide, this should be a picture of four of these little spatter piles that we made being logged as they cool down. And you can see that the insides of those are red and they're still very, very hot. It takes quite a few hours for these piles to cool down. If we were really on top of our stuff, we could get about eight piles done in a day, and then we have to recharge the machine and everything.

[Slide 32] From these little piles, we wanted to be able to figure out -- if we go back and hit the next button, you'll see that we get back to this diagram again. And so can we actually put numbers on this? Can we find where those spatter clasts no longer will fuse together based on different cooling rates and accumulation rates -- how fast could I pile up those spatter clasts -- and what was the actual cooling rate from each of those deposits.

[Slide 33] If you go to the next Slide, Slide 33, there are several other characteristics that should be correlated with high heat. There's two examples here. There's the hotter deposit on top and in that scenario, we were hypothesizing that we would be able to see many more connections, much more fusion between the clasts, and that we would also expect to see a lower width to length ratio. So these clasts would be more pancake-like as opposed to softball-like. The cooler deposit you can see below. The other difference is that we were expecting to see more void space in these cooler deposits because if those clasts are less fluid, they're not going to be able to drape into those voids quite as easily.

[Slide 34] So if you go onto the next slide, what you'll see is one of these little spatter piles up close and you can see that some of the gravel isn't completely incorporated. It just kind of sticks into the side of these clasts and the thermocouple rods are sticking out from the left side of that pile.

[Slide 35] The next slide, the data collection here that we are trying to get -- this is what the data looks like when we download it from the thermocouples. If you hit the button, you'll see that we are looking for the high temperature, which is the point of those arcs there. We also look for the cooling rate, which is the slope of that line. The final thing we get from these diagrams is the time that that deposit spent above 700 degrees, and remember, that's the glass transition temperature that we're working with. So the more time that you have above 700 degrees, the more fusion you're going to be able [to see]. The clast is going to be able to anneal during that time. So you would expect that to have a significant effect on what these clasts look like.

[Slide 36] If you hit the button again, you got to a FLIR image of these spatter piles. Using the FLIR, we were able to get the surface temperature of the clasts right before they came into contact with each other. That's important because even though you have this whole big clast, it has a bunch of thermal energy within it. All of that thermal energy isn't necessarily available to that boundary between those two clasts. So looking at that surface temperature, right between those clasts was actually really important.

[Slide 37] If you hit the button again, after these piles cool then what we would have to do is split them apart without destroying our clasts so that we could look at the surface of these materials.

[Slide 38] If you hit the button again, you'll see that one of things we measured was the amount of surface area that actually was fused between these clasts. This was sort of a lower to moderately low fusion between clasts.

[Slide 39] And if you hit the button again, you'll see one of the highest fused clasts here that just totally stuck to the other clast, and it was very difficult to break these part.

[Slide 40] Now if you go to Slide 40, you'll see this diagram again and what we were able to do is break up these clasts into fused and unfused spatter. So fused is red and unfused is black. And then plot them based on the cooling rates that we measured. If you hit the button again, the accumulation rate will pop up so that we can now plot our samples on there. You can see that all of the red samples are to the left of about 10 degrees C per minute on the cooling rate and most of the black ones are to the right of that cooling rate. There’s a couple of unfused samples to the left of that cooling rate and there's one about 7 and 8.5 or something like that.

These two suggested that there's something else going on here that's dictating whether we're getting spatter or tephra. The accumulation rate, you can see we didn't come anywhere close to accumulating material that turned into clastogenic lava flow. That's probably because we weren't really targeting that. We were simply trying to get this method to work. However, there was one eyewitness report of a spatter producing eruption that accumulated spatter so quickly that it did flow and they were able to estimate that at about 10 meters per hour.

So we're sort of getting closer on this diagram to constraining what forms spatter and what forms tephra, for example. But I wanted to see what else could be influencing this.

[Slide 41] If you go to the next diagram, I was interested in what's forming the minimum conditions for welding. On this diagram, you can see time above 700 degrees C on the Y-axis and so that's, again, how much time these samples experienced above the glass transition temperature, and then surface temperature. That's from the FLIR camera. And if you hit the button you'll find that there's a fairly good distinction here between the fused and unfused clasts and those two that are right on the either side of that line, the one below it had 0% welding and the one above it had about 0.6%, so it was very minimal. It was very, very tiny. So this is actually a pretty good constraint between these two sides of the diagram.

So, it turns out that you need to have, at least in this scenario, we needed to have about 30 minutes above 700 degrees Celsius and you had to start off with a temperature of at least 775 degrees to even get a little bit of welding at that point.

[Slide 42] If we go to the next scenario, we wanted to see then, are any of these hypothesized relationships true? Are there going to be more connections, more squashed class, and less void space in these hotter deposits.

[Slide 43] So if you go to the next slide, 43, the next couple of slides is going to be a whole lot of clicking to make things pop up. So we will try to get through this. The slides have a general format where there's going to be three diagrams and then each slide has a scale on the bottom left-hand corner. So in this case, with the more connections, all of the dots are going to be colored based on the gradient here. So the red dots are going to have a very low amount of connectedness and the sort of yellow up to the greeny-brown, yellowish color are going to have a very high amount of connectedness.

I'm just going to click through until all of the three graphs pop up and we'll just walk through them individually. Here we have time above [700 degrees] C and the high temperature from FLIR again. So this is that same diagram, how much time you have to fuse things, plus how high was that original temperature. And what you can see is that black clasts again are totally unfused and as you go up into the higher temperatures and the more time about 700 degrees, you do in fact get this gradation of fusion, which is great. And the highest amount of fusion occurs mostly at the higher times above 700 degrees Celsius.

And if we look at these other two diagrams, this relationship still holds true, although it's not quite as good, visually. For example, the two right-handed diagrams are both cooling rates along the x-axis and so you can still see 10 degrees C per minute boundary between the totally unfused and the mostly fused clasts, but you can see that there's a lot more scatter in how much fusion will occur. This relationship, if you hit the button again, it will show the conclusion, and that's that the amount of fusion between clasts is definitely related to how much time above 700 degrees these connections spent.

And that this relationship, especially if you get that high temperature from FLIR, then we can actually start to break these down into categories based on the percent of connection.

[Slide 44] If go the next slide, now we're going to test whether or not squashed clasts are associated with higher temperatures. We'll just get all those diagrams to pop up again and what you can see is that this relationship is not quite as good, and it's actually a little bit different too. If you look at the upper left hand diagram, you can see that as we go from lower temperatures, there’re two tracks we can take. We can take this lower track, which has the darker colors associated with it and, then there's also this upper track, which has more of the lighter colors associated with it.

The darker colors are the clasts that are more one-to-one ratio [in height and width], more softball like, and the pancake clasts are the lighter colored clasts, which we find to be at these not necessarily a higher temperature, but a much higher amount of time spent above 700 degrees C. For example, if you look at 850 degrees C on FLIR temperature scale, you'll see you run into this darker one, and then you run into a medium one, and you go into these lighter ones as you go, as you increase that time above 700 degrees C.

We can see this kind of relationship in the cooling rate as well. [For] these faster cooling rates, clasts are going to be more rounded and sort of softball like than the clasts that have lower cooling rates. So that all makes sense as well. Now, if you click the button, you'll get the grand conclusion for this slide. One of the things that's affecting this, why this is not as good of a relationship as we were hoping to see, is because, as you saw in the video, much of the way that the clast is shaped is going to be dependent on how it was created. I'm mushing that clast around. I'm kind of forming it into a ball. That makes it easy for me to pick it up and move it over to the spatter pile area.

This is actually kind of analogous to what's happening in nature because when those things are being thrown out of the volcano, they're flying through the air and they're getting twisted, and contorted, and they're deforming, so that they might not necessarily have an obvious shape when they land. This is basically showing that this relationship does hold true. However, there are external factors that can shape the clast during flight.

[Slide 45] If we move onto the next slide, the void space slide, we can get all those diagrams to pop up. The dark purple here, this is if you have a lot of void space, in these cases 10% was sort of the max that we could get. And then if you go up to the light purples, that's where we get almost no void space at all.

You can see on the upper left hand diagram again, as you go up in temperature and time, you start to get lighter and lighter purples, and you actually get your lightest purples at these highest time above 700 degrees C. And this relationship holds pretty well for cooling rate as well too, actually. If you compare cooling rate and time above 700 degrees C, this upper right hand diagram, there's actually a very good correlation between the temperature and how much void space there is between the clasts. So if you hit that button and get the grand conclusion, basically this relationship holds very true in our experiments and we think that this might actually be a good thing. We might be able to quantify natural samples using this relationship.

[Slide 46] Now, the next slide, this one has the number 46 on it, this is the vesicle mode slide, and I think everything should have popped up all at once already for you. Basically, what this is showing is, if you look at the scale bar on the left here, we have a dark brown clast with a lot of vesicles inside, a lot of little bubbles. And if you go down to the lighter colors, you have not so many bubbles at all, 10% or so. And so what we can see here, if we go to the diagram just above that, this is kind of a similar situation where the highly vesiculated clasts are along this track of less time above 700 degrees C. So this was more similar to the squashed clast relationship than to the connectedness relationship.

However, it does seem to hold pretty true with the cooling rate relationships as well. It just seems much more dependent on this time above 700 degrees C than anything else. Now, of course this was not something that we controlled for very well, with how much gravel we added. So that's going to influence how much gas is available to make these vesicles. Additionally, the more manipulation of that clast that we were doing, the more gas can escape out of it. So there’s a lot of different things that could be affecting this, but since we do see this relationship, that does seem to be a general trend that would hold true in the natural samples as well.

[Slide 47] Okay, so then 47, let's click through and get all these graphs to show up. Some of the gas doesn't get trapped in small vesicles. It's actually able to accumulate in a large central cavity in the middle of the clast. For our experiments, we were able to create piles that every single one of the clasts had a big void in it. And so those are colored the lighter yellow. And the piles that had maybe only one clast for every three, for example, are in the dark green. And what you can see with this -- if you look at the diagram just above the scale, again, and as we go to higher temperatures -- we're actually losing those central vesicles, those central cavities in those clasts that sat at the highest and hottest temperatures.

If you go down to the bottom right-hand corner, this graph shows you void space versus the percent of central cavity in the clast. So this x-axis is basically the same thing as the axis along the scale. And what you can see is as you increase the void space, and if your remember higher void space meant much cooler, there's a much greater variability in whether you're going to have a lot of large central cavities in your clasts. If you hit the button again, you'll see that we were able to show that these central cavities, which we see a lot in nature, they're more associated with clasts that cooled very quickly or they were just erupted at a cooler temperature to begin with.

[Slide 48] Okay, so that was a lot of data. Let's see how we can actually apply this to real deposits.

[Slide 49] If you go to the next slide, what you'll see here is the way that we used field data. This is an outcrop at Craters of the Moon, and we went and measured a whole bunch of features on every single one of the clasts in eight different outcrops. And you can see all of the clasts are outlined in this picture.

[Slide 50] If you go to the next slide, we wanted to measure the length, and the width, and the amount of vesicularity in the core. We also wanted to see if there were these big cavities in these clasts. The other thing [we wanted to measure] was just how connected they were. You can see in this upper clast, there's almost no connection. The Sun makes a pretty good case for how there's almost no connection between these clasts surrounding this upper picture.

Then in the bottom picture you can see that there's some distinction where this clast does not actually fuse to other clasts, but mostly where the red parts are in this photo, this is where that clast had totally fused to the clasts above it. This gradient was something that we observed in nature, and we were hoping that we could apply that to our data.

[Slide 51] If you go to the next slide, Number 51, what we see here is the range of connectedness within each deposit. You can see there's quite a lot of variability within each sample. Most of the samples clustered within 10% to 15% of the average of the range of connectedness. Since we're trying to quantify the deposit as a whole, taking the average of these values seemed to be a pretty good idea.

[Slide 52] If you go to the next slide, this is where we're going to try to extract all of this quantifiable information, this list of parameters down here in the bottom, from the data that we've collected so far. First of all, we have the cooling rate along the x-axis of this diagram and time above 700 degrees C on the y-axis. These dots again are broken up into the amount of connectedness in the experimental samples. We put the divisions between these groups on here with their values. What we can do is we can say based on the amount of connectedness that we saw in the natural samples, which ranged from about 10 to 35 [%]... If you hit the button, the little Craters of the Moon patch pops up there in the general vicinity of where we see many, many of the samples at Craters of the Moon plot, with regards to how much connectedness there was between the clasts.

Now, what we can do is we can draw down those lines to the cooling rate and we can find that we get about a six to nine degree C per minute cooling rate associated with those samples. Additionally, if we draw lines over to the y-axis, we can see that it's about 35 to 70 minutes above 700 degrees C for those equivalent experimental samples.

[Slide 52] Now, if we change this diagram and instead we look at, if you hit the button a couple of times, we'll get all of the information on here. The high temperature from the FLIR, that's the bottom axis, again, and the time above 700 degrees didn't change. We can take that information, the 35 to 70 minutes, and we can plot that on here. We can also correlate that with the amount of connectedness that we saw. And what we can do is draw those lines down to the x-axis and find that we get about 800 to 950 degree Celsius temperature, and I have it landing temperature here because this is the temperature right before the clasts touch.

This gives us a range of what these eruption temperatures were, the landing temperatures for Craters of the Moon. Now, to get accumulation rate, we're going to have to do a little bit of math.

[Slide 54] So if you hit the next button, what I was able to do is write a numerical model, and if you click through this what you'll see is how this model works. Basically, it deposits a clast, which cools, and you can determine the thickness of that clast, and then you can tell the program to erupt these clasts and pile them on top of each other, which then give you an accumulation rate of whatever you had determined. That model will calculate the cooling during that whole process. So the cooling is going to be affected by how much heat you're putting into the system and how quickly you're putting that in there.

[Slide 55] So if you go to the next slide, and then you play this little animation, what you're going to see in this upper window is the temperature profile through that deposit. So this is going to show that there's a big temperature increase where that first clast is deposited and as subsequent clasts are deposited on top of it, you'll see that peak shoot up there again, until the whole thing starts cooling as one. And on the bottom what we have is the temperature right on top of that clast, so right where we had put that thermocouple in the experiments. And so what you'll see is that temperature first we'll start decreasing and then after a new clast is put on there, it will start increasing and the system will peak out after that third clast is deposited and then you'll get a nice sort of cooling curve, which you can get that cooling rate from.

[Slide 56] Okay, so if we go back to our list of things we're trying to learn about Craters of the Moon spatter, this graph that is now in the top part of the screen is showing the results from the modeling spatter clasts. You can see two lines here: one is the 10 centimeter line, and one is a five centimeter line. Five centimeters, that's basically how thick these clasts were in the model. And there's a green region between these two. This is sort of the region that we expect. This is the region that is covered by most of the clasts at spatters at Craters of the Moon. The clasts are usually between five and ten centimeters thick.

Now, however since this model is a one-dimensional model, so that means that all the heat is just being transferred between the clast. It's not going out the edges. It's not really being lost in any other way. What we have decided to do is to use the five centimeter clast curve here to really get our numbers off of, because that's going to better represent how much heat we're losing out of the sides as well.

If you put your Craters of the Moon patch right on the graph based on the six to eight or six to nine degrees C per minute cooling rate, what that corresponds to is actually about 0.5 to two meters per hour accumulation rate.

[Slide 57] So if you go to the next slide, this shows you one of these spatter cones at Craters of the Moon that was about 30 meters high. And if we use the accumulation rates that we just calculated using our model, what we can calculate is the eruption window for how long it would've taken to build this spatter cone, which was about 15 to 60 eruption hours to emplace.

Now, this method doesn't necessarily do a very good job yet of determining if there were pauses in the system. So this is why I say eruption hours. Those eruption hours could have been spread out. There could have been chunks of eruptions going on, but this is the total time of spatter activity at this volcano.

[Slide 58] Okay, so now, next slide, we're going to try to apply this to the moon. This is an artist’s rendering of the Lunar Reconnaissance Orbiter and this it's been taking really good pictures of the surface of the Moon.

[Slide 59] If you go to the next slide, one of these pictures that it's taken is of a region called the Marius Hills. What you can see in this image is that there's these little bumps all over and that these bumps are kind of irregular. They're not in a particular pattern. They're not along a line. They don't have the same structures as the craters. You can see that there's a bunch of craters in here that have very steep walls. They have a big hole in the middle, the whole crater part. These little bumps are thought to be something else. They've been proposed to be little spatter cones.

[Slide 60] If you go to the next slide, one of these papers that proposed this to be some kind of spatter feature was able to get a digital elevation model of the area, make a digital elevation model, and from that we can get a height of the spatter cone rampart. You can see there's about 100 meters on the right in one of these diagrams. You can see it's about 100 meters from where that change in slope really starts to occur.

[Slide 61] If we go back to our summary slide here, we can take the landing temperature that we got from our experiments as well as the time above 700 degrees C because these seem to be the strongest dictators of whether you're going to get spatter or not. So we're going to take those to be similar. And then what we're going to do is we're going to look at the thermal regime of the Moon. There's no conduction or convection in the atmosphere, because there's no atmosphere. So all of the heat is lost through conduction through the bottom of the flow and radiation out into space. This is much less efficient. So what we find, if you click the button again, is that moon spatter is probably going to have a much lower cooling rate. In the numerical models that I ran I found that many, many of them were right around four degrees C per minute.

So we take this information that we have and I was able to run the model for lunar conditions and it turned out that to get to the appropriate range of time above 700 degrees C, so we have 35 here -- to get up to 70 minutes, I had to add another run of about 1,000 degrees C. So it's very possible, if you hit the button again, that what you'll find is that the landing temperature, because of this lower cooling rate, it might've actually been higher in these lunar situations.

To figure out the accumulation rate, what we do is we take the low end, the 35 minutes, and the high end, the 70 minutes, and you can hit the buttons to get those to pop up, and then look at the accumulation rates. The lowest possible accumulation rate we can get from that is about one [meter per hour]. That's where the 1,000 [degree Celsius] line comes down and intersects the 35 line. The highest we can get is about 10 meters per hour, right around where the top of those two lines come -- would intersect around 1,000 degrees C on that graph. So we get this one to ten meters per hour accumulation rate.

If you hit your button again, then we can calculate what a 100 meter cone would've taken to form. It would've taken, using this sort of range of accumulation rates, 10 to 100 hours to actually form these lunar spatter features. It's very likely that we're sort of more in the lower end of these accumulation rates. So the 100 hour number is actually much more likely, but there's some more discussion and evaluation that has to go into these numbers for sure. What we can see here is now we have an estimate for earth's volcanoes and for lunar volcanoes. They're not too far apart, but the sort of thermal regime differences between the two result in possibly longer emplacement times for these lunar volcanoes.

[Slide 62] All right, so if you go to the next slide, we'll begin our conclusions here. So hopefully, I showed you that you can go into the field and study the rocks. Then if you can recreate what you see in the field, then you can start to explain some of these eruptions that we don't have any eyewitnesses for, either older earth eruptions or eruptions where we have very little information about, such as places on the Moon. We can start distinguishing between where we see cinder or spatter, and maybe coming up how long it took to form those features, for example.

[Slide 63] To go to the next conclusion, many different physical parameters were correlated with the thermal history of the deposit, including the length to width ratio, the vesicularity, and how well fused those clasts were. The amount of fusion seemed very well correlated, and that is something that we can actually apply to other eruptions, at least within the range of chemical similarities between the experiments that we did, which was more basaltic type composition.

[Slide 64] Number three, there seemed to be a pretty good cutoff at 10 degrees C per minute between the fused class and the not fused class. So I think that this is a pretty good relationship that we can apply to mapping areas, for example, of spatter versus scoria.

[Slide 65] And the fourth and final conclusion -- because of the lack of convection in the atmosphere, there's going to be much slower cooling going on at these volcanoes. So to actually build up a spatter cone, as opposed to have a clastogenic flow, we probably are going to require slower accumulation rates, and have a more extended duration of these eruptions for something like the Marius Hills, for example.

[Slide 66] Okay. So last slide is thank you all very much and if you have any questions, I'd be happy to answer them.

Jeffrey Nee: Great. Thanks, Erika. Well, we'll give people a minute to unmute and stuff but I want to say thanks for that. That was really, really cool and I just love that video. That was just a great video. I've never seen that before. Of course, we do want to be respectful of your time. I know it's just about 1:00 right now. Do you need to go off for something else or can you stick around for a few minutes?

Erika Rader: I guess I talked longer than I thought I would, but I'm fine to stick around and answer questions.

Jeffrey Nee: Great. Well, people know they can interrupt me but I just want to start with some of my questions. So if we go back to Slide 61, one of my main questions was that you were saying that in order to get the Moon modeling right, you had to increase that landing temperature, or the estimates of your landing temperature. Does that kind of make sense that lunar lava might be, on average, hotter than current earth lava?

Erika Rader: Yes, there's a lot of speculation, or I guess, science-based [hypotheses], where people have tried to figure that out. There's definitely morphological physical evidence for hotter lavas, such as lavas that seem to coat features and extend very, very far, but also, just the thermal regime of the lack of convection in the atmosphere. We don't really know, but there's less evidence for a developed groundwater system that would encourage more cooling like we see here on Earth. So yes, I think there's a lot of different indicators that would say that that's realistic.

Jeffrey Nee: Let's go back to the video. That's Slide number 30. I just wanted to ask, is all that equipment that you're using the same equipment that people use when they're actually working with -- I guess it is real lava, isn't it, technically?

Erika Rader: Most people don't go out to the lava flow with a big metal paddle like that but you mean like the safety equipment?

Jeffrey Nee: Uh-huh.

Erika Rader: There's not a lot of real good reason to walk up to a lava flow and be in front of it for very long. When you see those movies where they have the people in the spacesuits, they're just kind of there to be there. So I wouldn't say that that's a common thing. The other thing is that the only reason we can stand there and do that clast manipulation is because we stop pouring the lave like really quickly. If it continues to pour, it's just there's so much heat radiating off to you that that equipment doesn't help at all. So it makes it tolerable to stand next to a ten pound pile of lava for two minutes, but you get any more volume than that and you've got to kind of run away and let it cool off.

Jeffrey Nee: Was that you stepping on the lava?

Erika Rader: That was not me. I do not advocate for the destruction of your footwear, but no. It's a very unique substance that people like to experiment with, and I think throwing things at it, and poking it, and stepping on it are kind of a normal way to experiment with that. But that was not me.

Jeffrey Nee: Okay. And you were saying, talking about the layers -- the thickness of each spatter but how much mass is in each one that you're handling?

Erika Rader: For the experimental clasts, geez, let's see. We didn't actually end up weighing any of them but they're pretty heavy. It's still rock. I think it's probably 15 to 20 pounds maybe. I'm not sure.

Jeffrey Nee: That's fine. And then I had some questions about the vesicles. I know I'm jumping around all over the place but the vesicles, your measurements were done by percentage of volume, right, of the total clast? Slide 46?

Erika Rader: Mode is this measurement that we use in geology, that was developed when you have a thin section. You take a little slice and then you basically just measure the surface area of whatever it is that you're looking at. So it's a 2D measurement that compares the surface area of vesicle versus rock.

Jeffrey Nee: Okay. I was wondering how you measured that in a whole clasts but okay, that makes sense.

Erika Rader: There is some potential to develop a way to use density to figure out how much vascularity is in your clast, but yes, these clasts were very large, and you can't get the one in the actual natural deposits. There's no way to extract a single clast and do anything to it. So that's why we used mode because that was kind of the only thing you could measure. That would be a useful way to measure on, say, if you just have an image from a Rover, that's going to be what you're going to see, is that surface area.

Jeffrey Nee: And then my last big question was what kind of classroom applications can you think of? I'm trying to think of can kids melt wax and create these spatter patterns, and do measurements on those. Or have you thought of any of that in your work about how they can apply it to the classroom?

Erika Rader: Yes, so this project -- I actually started on this project during my undergrad when there was this type of wax that you could get -- it's called polyethylene glycol wax and it forms a crust just like lava does and still has kind of a molten interior. So you can still get that transition of kind of deformable but kind of sticks together, and that stuff is really good for classroom demos. You can make lava flows. You can show how lava flows can inflate, and grow, and make tunnels, and tubes and all this stuff. And so for spatter, you could definitely do -- have someone do a more rapid accumulation versus a slow accumulation and try to find that boundary for the properties of the wax as well. That would be a pretty cool experiment.

Jeffrey Nee: And that's polyethylene glycol you said?

Erika Rader: Yes, PEG wax is what it's abbreviated as, and then there's a couple of different viscosities. Six hundred is the best, given the thermal properties.

Jeffrey Nee: I've been stuck with baking soda and vinegar for all of my volcano demos.

Erika Rader: Yes, that's a useful one as well. Maybe you could put baking soda and vinegar inside of the wax and see what happens.

Jeffrey Nee: That's great. Okay, let's see, are there any other questions?

Man 2: I had a quick one. I was interested in what the X axis was on the bottom right graph on Page 47?

Erika Rader: Yes, sorry that -- so that's just the percentage of clasts that have a large cavity. So the dark green dots, those are at 33% and, then basically, the whitish dots, those are at 100%.

Man 2: Okay. Thank you.

(Adrienne Provenzano): Hi, this is Adrienne Provenzano. I'm a solar system ambassador and I had a question about the Slide 36 photo where you were showing the thermal energy and I was wondering what kind of camera you used and if you do a lot of experiments like that?

Erika Rader: So that's a FLIR camera. It basically measures infrared energy and I don't know -- they're fairly easy to get a hold of. I don't know how much they cost but those are definitely really useful for any researcher who's doing the lava experiments at Syracuse, or if you're going out and you're walking around on a recent eruption, and you want to know where the hottest stuff is, these cameras are really useful for that.

(Adrienne Provenzano): Do you do a lot of work with taking photographs and analyzing them?

Erika Rader: Yes. I guess the most analysis that I've really done with these photos is simply looking at where the high temperatures are and what they are, but yes, it's sort of a routine measurement that we do.

(Adrienne Provenzano): Great. Thank you.

Woman 1: FLIR makes the camera attachment for android phones and it's $200.

Erika Rader: Okay, cool.

(John Hooten): This is (John Hooten). I was wondering two questions: how you think the different gravitational field on the Moon will affect the spatter formation and have you looked at extrapolating to different materials in cryovolcanism?

Erika Rader: Well, yes. So the gravity situation definitely is going to affect two parts about the spatter -- well, three parts I guess if you really want to go into the nitty-gritty. The first is that it's going to affect how quickly the material is ejected. The gradient in the vacuum/gravity issue is really going to send material out much faster than on Earth. Plus, then it won't be pulled back to the surface quite as rapidly. So it's going to be radiating in the atmosphere or the void of atmosphere for longer. So it's going to be losing heat at a different rate during that process. And then when it finally lands, then it's going to be -- it's not going to have as much force, first of all, when it lands. So it's not going to deform as much in that regard and then it's not going to deform into the void space as much when you have one that's just sitting there above the glass transition temperature.

So all those things are definitely important and would need to be calibrated to the gravitational system and so my big brilliant plan to do that is to install a giant furnace inside of the vomit comet and have NASA fly me and the lava flows in the atmosphere and do some of these experiments in [microgravity]. I think that's the next step.

And then cryovolcanism. I haven't thought about it too much. I think my knowledge of what could even form in cryovolcanism is fairly limited. There's certainly a lot of experiments that you could do to replicate what might happen. So that might be a really interesting avenue for this research as well.

Jeffrey Nee: Great, and I should mention that a Museum Alliance Member recently asked me for information on infrared cameras for an exhibit, and they're great to use for educational outreach. Kids don't get to see it in infrared, and now, the IR cameras are just getting, like all technology, they're getting cheaper and more available. It's great to just show kids what they look like infrared, and show when you touch something, it changes the infrared view of things. So if you're interested in that just let me know and I can send you the same research that I gave to them.

All right. Any other last minute questions? I think we can start to wrap it up. We're about 12 minutes past the hour. Okay, great. Erika, thank you so much for spending the time with us. This was a really, really great talk, and again, I just can't thank you enough for all the great imagery. The volcano imagery alone is worth it because all of my volcano imagery is so old, and it's great to have new stuff.

Erika Rader: Yes, sure. If you need anything else specific, let me know. I have a ton of it.

Jeffrey Nee: Great, and thank you to everyone for joining us today. Remember that this talk will be recorded and archived on the Alliance site and you're encouraged to share this presentation with your colleagues such as your education staff and docents. If you have any further questions about this topic, either now or in the future, always feel free to email us. Again, my name is Jeffrey Nee and my email address is jnee@jpl.nasa.gov.

Our next telecon will be on Thursday, April 13th at 12:30 p.m. on the 30 years after supernova 1987 and we hope to hear you there. Erika, any last words.

Erika Rader: No, thanks very much for having me. This was great.

Jeffrey Nee: Great. Thanks, Erika. Thanks everybody.

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